Redesign of an automatic crown cap punch press machine and implementation of a pro-active maintenance strategy: A Case study for ZXY, Zimbabwe

Tawanda Mushiri
Department of Mechanical Engineering
University of Johannesburg
P.O Box APK 524
Johannesburg
South Africa
tawandanda.mushiri@gmail.com, tawandamushiri123@hotmail.com

Romana E Mundondi
Department of Mechanical Engineering
University of Zimbabwe
P.O Box MP167
Mt Pleasant
Harare
Zimbabwe
cae.ethelr@msn.com

Charles Mbohwa
Faculty of Engineering and the Built Environment
University of Johannesburg
P.O Box APK 524
Johannesburg
South Africa
cmbohwa@uj.ac.za

Abstract

During a machines lifespan, it reaches a point where it no longer performs as it used to in its early age. When this happens, one of the options to consider is the procurement of a new machine. However unavailability of funds may always hinder this process leading to the next best solution, redesign (design modification). ZXY is a metal and plastic packaging company situated in Zimbabwe. One of their production processes produces crown caps for carbonated drinks. Two machines are available for this process, the SACMI Press machine and the Callahan press. This paper involves the redesign of a Callahan punch press machine for crown caps at ZXY and the factors leading to the design modification .It looks at the design of the punching tool, which is the punch and the die, the automation of the guard. After the redesign, the implementation of a proactive maintenance strategy is then looked at for the redesigned machine.

Keywords
Redesign, Punch Press, Crown cap, Proactive maintenance, ZXY.

1. Introduction

ZXY is a company situated in Harare. It focuses on the manufacture of metal and plastic packaging for things such as paint, shoe polish, floor polish, fruit juices and detergents. They also manufacture crown caps for beer bottles and carbonated drink bottles. ZXY has existed in Zimbabwe for 66 years since 1950 and has grown considerably over the years. The company is a metal and plastic packaging manufacturing company. Initially, the plastics packaging division and the metal packaging division were situated at different plants in Harare. As of to date, both divisions are operating under one plant, ZXY is divided into two sections, the plastics packaging division and the metal packaging division. The plastics packaging division is responsible for the production of plastic containers for the packaging of milk, fruit juices, sauces, and their tops. The shape of the product depends on customer requirements. Two processes are involved in the Plastic Packaging Division which are Injection moulding and blow moulding. The bottle tops are produced through injection moulding only. The plastics section is divided into 3 sections according to the machines involved. The metal Packaging division manufactures

- Open top food cans
- Motor oil cans
- Paint and chemical cans
- Roof seals and crown caps
- Shoe and floor polish tins

The SACMI and the Callahan Presses are used for crown cap production. The MB presses are used for floor polish and shoe polish tins. The 314 press is used for food cans. The SACMI and Callahan presses are used in the production of crown caps. The SACMI Press is a recent machine compared to the Callahan which is an old model in need improvement of or replacement to alleviate the problems being encountered when it is in use. Crown caps are items made from tinned metal used to fit on top of beverage bottles to seal and lock the contents of the bottle from being easily opened and for preventing any item from escaping out or from entering into the bottle. The crown cork is made from tinned metals with the interior part in contact with the contents of the bottle being covered off by a plastic disc. For crowns, machines used are the Callahan and the SACMI press machines.

1.1 Background

When running smoothly the Callahan press produces approximately 1.3 million crown caps per 24 hours but of late there has risen a need to redesign the machine so as to minimize die misalignment, develop an effective maintenance strategy to reduce down time and increase safety of the operator at point of operation by developing a control system for the removable guard barrier. The Callahan machine is an old machine that has begun experiencing problems and is lagging behind in terms of other features in comparison to the recently designed punch press machines for example the recently acquired SACMI press. Also with the advancement of technology and with the continuous advancement in the engineering field there is always room for improvement in terms of machine design. With the ever development of new machines, old model machines may easily be replaced with improved versions. However, the procurement of a new machine may prove costly. Looking at the poorly performing Zimbabwean economy, this procurement is not as easy as it used to be when the manufacturing industry was fully operational (most manufacturing companies have closed). Instead of procuring a new machine, the already existing machine may be redesigned to improve efficiency, improving its performance.in engineering the term design modification is used to describe the changes made to a process or machine during its use with a view to increase efficiency of the system or process. The advantage of design modification is that it is cheaper compared to buying a new machine altogether. With design modification, problem areas are identified and design changes made to those areas to curb the problem areas. The company that manufactured the Callahan press in 1972 has since close and the availability of spare parts is a problem. However with design modification, spare parts can also be made readily available since the designers will be at hand. This is referred to as import substitution. Instead of importing spare parts. The spare parts are made readily available locally. Locally available goods are always cheaper than imported goods.

2. Literature review

Punch presses (presses for partial separation – cutting or perforation) are machines used for making work pieces from metal sheets by numerically controlled process of cutting and perforation. Compared to the original definition of machining centers as it is defined in machining technology, these machines can also be named as processing centers for cutting and perforation (Blanuša, Milan , Dragiša , & Slobodan, 2011). A punch press is a machine used for piercing holes or other openings in sheet metal or plate. The tooling or die set consists of two parts: the upper male punch and the lower female die. The punch is fitted to a ram or slide, which moves down and up by mechanical, hydraulic, or pneumatic power. The punch pierces the material and enters the lower die. A punch press can be small and manually operated and hold one punch and die, or be very large and computer operated.

2.1 Working principle

In general the punching action is accomplished by a vertical moving ram that forces the punch through the material and into a die through which the resulting slug is ejected. Additionally, a device to hold the material in place as the punch is withdrawn, called a stripper, and is often an integral part of the punch tool. The press ram may be activated manually, mechanically, or hydraulically. The manual press, usually a tabletop model, is capable of generating about four tons of force. These machine tools perform a large number of strokes per time unit while the desk with a metal sheet moves in the planar coordinate system, which allows cutting straight-line and curvilinear contours. The metal sheet shaping machines can be, depending on the driving mechanism, divided into mechanically (crank presses), hydraulically and electrically driven machines. They are used in applications in small series and individual production for metal sheet processing to obtain .Work pieces of different geometric shapes, as well as machines for unconventional processing (machines for LASER based metal sheet processing and water-jet processing machines). (Blanuša, Milan , Dragiša , & Slobodan, 2011)There exists also the possibility to integrate systems for manipulation of work pieces with the machine and obtaining in this way flexible technological modules for the processing of metal sheets. One of disadvantages of these machines is the requirement for high values of breaking force for processing thicker and materials of greater strength. Recently, this problem is solved by integrating these systems with LASER based systems, so that the LASER is used to warm-up the metal sheet in the processing area thus reducing the processing power for penetration. By integrating these processing types the concept of hybrid and hybrid processing machines are introduced, which is one of the contemporary trends in the development of machining tools, both for deformation based processing and classical machining based processing. As disadvantage of these machines the curvilinear surface roughness is considered and, consequently, one of possible directions to solve this problem is application of combined laser-punch machines. Programming of the machines mentioned above plays an important role in their implementation and use. Similarly to standard machining tools, machines for unconventional processing of metal sheets and punching and cutting machines can be programmed manually and automatically.

3. Materials and Methods

To gain a full understanding of the Callahan press machine, site visits were carried out to the ZXY for a period of a week. During the visits, knowledge of the Callahan machine was gathered. And through observation, problems associated with the machine came into light. Operators of the Callahan who work with the machine also had their inputs concerning the problems they are facing with the machine and also brought to the spotlight the issue of maintenance problems associated with the machine.

4. Design and discussions

In general the punching action is accomplished by a vertical moving ram that forces the punch through the material and into a die through which the resulting slug is ejected The main hazard of a punch press machine is where the punch and die come together to form the product. The impact can have a crushing, cutting or shearing motion, which creates a risk of having a part of the body of the machine operator crushed or cut when they come in contact with the moving parts. Below is a list of factors to be considered in guard design.

4.1 Basic rules for guard design

In circumstances where intrinsic safety is not achieved through the design, machinery guarding will be required to eliminate any remaining hazards. The primary function of a guard is to provide a physical barrier between a worker and the dangerous parts of machinery or plant. When selecting controls such as guards, careful attention to design and layout at the outset can eliminate many of the risks to safety and health and avoid later problems.

4.2. Basic rules for guard design

Avoid second best when designing a guard.

Some of the basic rules for guard design are:

• ensuring materials used are of suitable strength and good quality;

• recognizing that simply having any sort of guard may not be enough. Poorly designed or inappropriate guarding is known to contribute to injuries. Ideally, a guard should be custom designed for the machine and the work process;

• considering carefully the environment in which the guard is used and the needs of operators and maintenance workers; and

• If a guard is used from another machine, checking carefully to ensure that it:

- is not defective;
- If it's the target machine;
- is of suitable strength and quality for the new application; and
- achieves the aim of controlling the risk.

When considering the need for guarding, consider operational and non-operational parts of the machine.

Start with obvious operational parts such as:

- Rolls, for example calendars and flour mills;
- Saws, for example circular and band saws;
- Drills and drill chucks;

- Cutters in metal working machines, including the blades of guillotines and the tools of power presses; and beaters.

Then consider non-operational parts such as:

- Chains and sprockets;
- Belts and pulleys;
- Gears including rack and pinion sets;
- Shafts, plain or threaded; and
- Flywheels.

Consider other safety and health issues

In determining the most appropriate guard design for the hazard, risk and machine, other issues or risks should be considered. This is part of the holistic risk management process - see Section 2.4 of this code.

Guarding can also play a useful role in dust and noise reduction. In many cases, issues of wear, heat and ventilation affect operating efficiency and may have consequences for safety and health.

Selection of material for guards

The selection of material from which guards can be constructed is determined by four main considerations. These are:

• Strength and durability, for example use of non-metallic materials in corrosive environments;
• Effects on machine reliability, for example a solid guard may cause the machine to overheat;
• Visibility, for example there may be operational and safety reasons for needing a clear view of the danger area; and
• The control of other hazards, for example the use of a material that will not permit the ejection of molten metal.

(Commission for Occupational Safety and Health, 2009)

4.3 Design of the punching tool

Material for the punching tool is **tungsten carbide**

Properties of Tungsten Carbide

Young's modulus $E = 530 - 700\text{GPa}$

Modulus for rigidity $G = 243 - 283\text{Gpa}$

Poison ratio $\upsilon = 0.2 - 0.22$

$\sigma_y = 530 - 770\text{Gpa}$

Ultimate tensile strength $UTS = 841\text{MPa}$

Force required the crown press to press 903kN

Force required to press $F = 0.7tL(UTS)$

$=0.7 * \left(\frac{2.1}{1000}\right) * 841 * 10^6 * 0.73049$

Where;
t is the sheet metal thickness,

L is the total length sheared (perimeter of the shape), and

UTS is the ultimate tensile strength of the material to be punched.

T = Fr, Where F is force, r is radius, T is torque, $r = 0.365\ m$

Thus $T = 903x10^3 Nx0.365m$ =329595Nm

P = Tw

For finding the value of w. Assuming the ram moves 41 strokes per minute then

N = 41rpm, $w = \frac{2\pi N}{60}$, $w = \frac{2\pi x41}{60}$; = 0.071rad/s; **P = Tw,** $P = 329595x0.071$, = 5.667kW. Therefore to exert a force of 903kN of the material, 7.6 HP motor is selected.

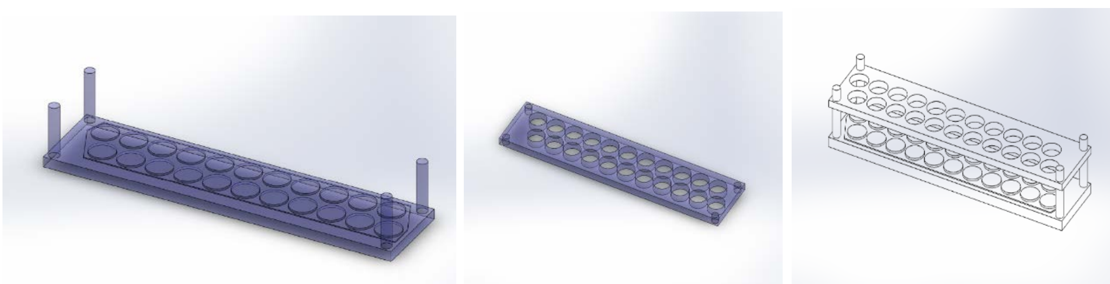

Figure 1. a.) Punch b.) Die c.) Assembled punching tool

4.4 von-Mises stress calculation
Maximum Distortion Energy Theory

This theory is also known as the von Mises Theory, looks at the total at failure and compares it to the energy in a uniaxial test. (Maxwell-Huber-Henky-von Mises). The energy is the energy associated with the change of shape of a material rather than change of volume. Any elastic member under load stores energy like a spring and the energy is termed distortional energy. It is accurate to ductile materials, it is used to predict yielding of materials under any loading conditions comparing to simple uniaxial tensile test.A structure is safe when the maximum value of the distortion energy per unit volume in the material is smaller than the distortion energy per unit volume required to cause yielding in a tensile test (Khurmi & Gupta, 2005).

U$_d$ = $\frac{1}{6G}$ $(\sigma_1^2 + \sigma_2^2 - \sigma_1 \sigma_2)$

Where

U$_d$ is distortion energy

G is shear modulus or modulus of rigidity

G = $\frac{E}{2(1+\upsilon)}$ where υ= Poisson's ratio

At the instance of yielding in a uniaxial tensile test, the state of stress in terms of principal stress is given by;$\sigma_1 = \sigma_y$ (Nisbett, 2006)

$$U_d = \frac{1+\upsilon}{3E}\sigma_y^2$$

Taking $E = 530\text{Gpa}$

$\upsilon = 0.2$

$\sigma_y = 530\text{Gpa}$

Then

$U_d = \frac{1+0.2}{3(530x10^9)}(530x10^9)^2$

=636Gpa which is the distortion energy

$\sigma_{vm} = (\sigma_1^2 + \sigma_2^2 - \sigma_1\sigma_2)^{0.5}$

$\sigma_{vm} \geq \sigma_y$

Where

σ_{vm} is von-Mises stress

σ_y is yield stress

Assuming combined torsion and bending/axial stress or pure torsion

Then $\sigma_{vm} = (\sigma_x^2 + 3\tau_{xy}^2)^{0.5}$

$\sigma_x = 530\text{GPa}$

$\tau_{xy} = 0.577\sigma_y$

$\tau_{xy} = 0.577(530x10^9)$

=306GPa

Therefore $\sigma_{vm} = [(530\text{x}10^9)^2 + 3(306\text{x}10^9)^2]^{0.5}$

=750GPa

Assuming pure shear or pure torsion σ_x=0. If σ_x=0, then

$\sigma_{vm} = \sqrt{3}\,\tau_{xy}$

$\sigma_{vm} = \sqrt{3}\,(306x10^9)$

=530GPa (theoretical value)

4.5 Automation of the guard

Below is a ladder diagram developed through the SMT client for PLC programming? It basically shows the way the PLC will witch off the machine when guard is removed.

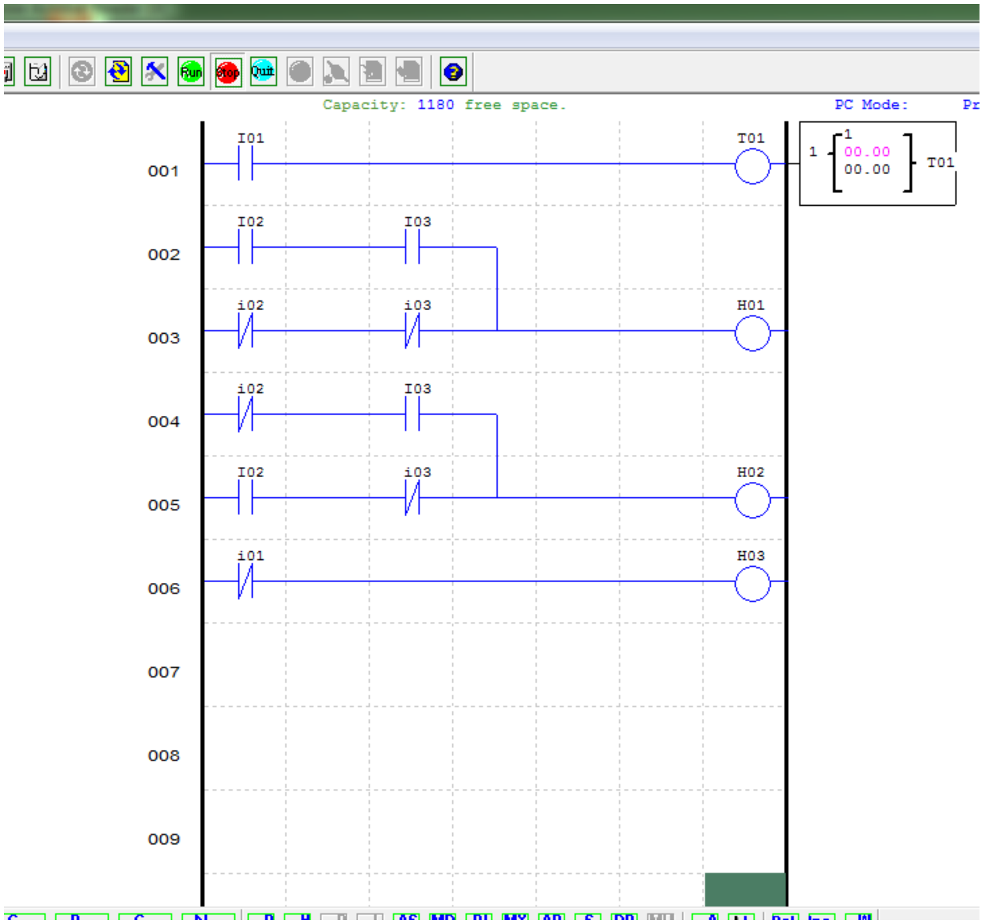

Figure 2. PLC programming

Before the addition of presence sensing devices, the guard already existing should meet the criteria discussed in chapter 2 under machine safety. As per observation, the guard meets the standards thus presence sensing devices have been added. Below is a description on how they will work. There are 3 inputs involved and all of them are pressure sensors. Sensor number 1 is situated on the guard handle. When the operator wants to remove the guard they handle it through the handle. The other two sensors are on both ends of a horizontal bar that supports the guard. So when the guard is on, it will be in contact with both sensors, when the guard is off. When guard is off then the sensors with not be in contact with the guard. The idea is that when the operator places their hand on the handle the sensor will be activated, activating 10 second timer. When the hand is removed, the timer stops and the sensor will be deactivated. When the 10 seconds have lapsed and the sensor is still active then then sensor 2 and 3 are then activated for sensing. The sensors 2 and 3 are only active when sensor is active. When both sensors, 2 and 3 are active then it means the guard has been completely removed and the machine is stopped automatically. The machine has to be started manually after this.

4.6 Stress analysis

Stress analysis was carried out for the punch and the die to determine if the design was safe or not. Below are diagrams showing the showing the results of the analysis. Both the die and the punch are safe.

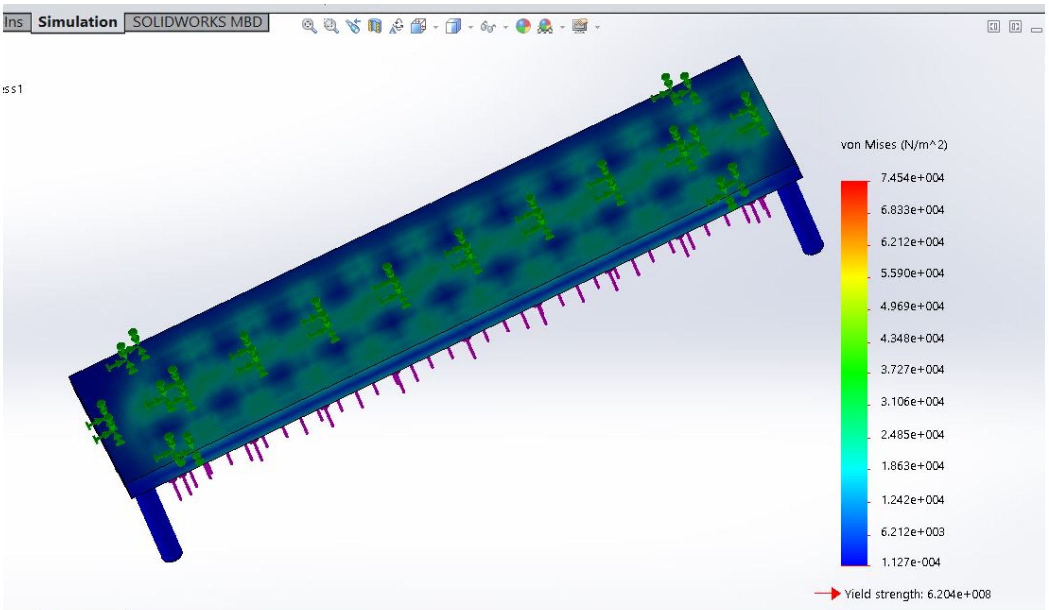

Figure 3. von Mises by Solid Works

In this section, the cost of the redesign components versus buying a new machine altogether will be considered.

4.7 Bill of Materials

Table 1. Bill of materials

Components	Quantity	Price Apiece (Us$)	Total Price
Pressure Sensors	3	60	180
Punching Tool	1	10000	10000
Total			10180

A new crown press machine to perform the same job as the Callahan machine costs approximately US$500 000. This is a large sum to use all at once and considerably a huge amount. Looking at the difference between the 2 values US$489 820,a company may opt to implement design modification in stages. This is reasonably affordable and as new problems arise the machine may further be modified again while preserving the company's cash reserves. Design modification as will described in chapter 1 works hand in hand with import substitution. Instead of importing spare parts from outside the country, the parts can be made locally corresponding to the designs through appropriate technology. It is clear that design modification is cheaper than buying new machinery and is one of the bet initiatives that may be adopted as a way of saving funds but improving efficiency and value.

5. Recommendations and Conclusion

Introduction and the implementation of design modification is a good initiative. Buying new machinery is costly and the cost of transporting it into the country is also high. During use all machines are bound to face problems and repairs. For imported machines the spare parts are almost always never available and need to be imported as well. This may lead to prolonged downtime in the case of repairs which require the machine to shut down. Every hour a machine is not in use, considerable amounts of money are lost and the for line production, the whole line is disrupted .design modification may be implemented in conjunction with the application of appropriate technology which makes use of locally available technology that decentralized, labour intensive and small scale. Local engineers may be used to come with the engineering design modifications to counter act problems and increase efficiency of machines.

When design modification is implemented successfully, even the availability of spare part will not be a problem anymore. Parts may then be made available locally for the local design. With the availability of spare parts maintenance can be done and implemented successfully. Design modification and import substitution work hand in hand in providing alternative solutions for companies suffering through the poor performance of the country's economy at large. As per observation, there are a lot of old machines at ZXY and other companies in Zimbabwe. Instead of engaging the money consuming new machine procurement, the implementation of the initiatives shown below is bound to have a positive result on the national industries when implemented correctly.

Figure 4. New way of design

5.1 Conclusion

The three practices below work hand in hand and each stage requires specifically trained personnel to carry out the required tasks. The adaptation of these initiative will be beneficial to the country as services and goods would be made available locally. At a time when the country is face with the highest levels of unemployment, this is an opportunity for job creation in the industrial sector. This also has an advantage of preserving the country's foreign currency reserves. The most obvious advantage is that it will save a lot of money compared to trying to buy new machinery.

6. References

1. Akinyem, O. O., & Onawoga,, D. T. (2010). Development Of Equipment Maintenance Strategy For Critical Equipment. *Pacific Journal Of Science And Technology*., 11.

2. Blanuša, V., Milan , Z., Dragiša , V., & Slobodan, V. (2011). THE SPECIFICITY OF PUNCH PRESSES PROGRAMMING. *Journal For Technology Of Plasticity, Vol. 36 (2011), Number 2* .

3. FREDRIKSSON, G., & LARSSON, H. (2012). *An Analysis Of Maintenance Strategies And Development Of A Model For Strategy Formulation-A Case Study.* Göteborg: CHALMERS UNIVERSITY OF TECHNOLOGY.

4. Adale, M. A. (2009, May). EVALUATION OF MAINTENANCE MANAGEMENT THROUGH BENCHMARKING IN GEOTHERMAL POWER PLANTS. Iceland: Faculty Of Engineering – Department Of Mechanical And Industrial Engineering University Of Iceland.

5. Arun S, Rajendra, S., & Bongale, V. (2014). Automatic Punching Machine: A Low Cost Approach. *International Journal Of Advanced Mechanical Engineering.*, 509-517.

6. Bryan, L. A., & Bryan, E. A. (1997). *Programmable Controllers Theory And Implementation.* Georgia: Industrial Text Company.

7. Bullimore, K. (2015). *Maintenance Strategy* . The Open University.

8. Commission For Occupational Safety And Health. (2009). *Code Of Practice Safeguarding Of Machinery And Plant* . Peth .

9. Engineers, S. O. (N.D.). Punch Presses. *Fundamental Manufacturing Processes Video Series Study Guide*.

10. Giraud, L. (2009). *Sécurité Des Machines - Prévention Des Phénomènes Dangereux d'origine Mécanique, Protecteurs Fixes Et.* Quebec: IRSST.

11. Goyal, P., Srivastava, G., Singh, R., & Singh, N. (2015). Review On Pneumatic Punching Machine And Modification In Punch Tool To Reduce Punching Force Requirement. *International Journal Of Engineering Techology Science And Research, 2*(2), 129-130.

12. Harwell, M. R. (N.D.). Research Design In Qualitative/Quantitative/Mixed Methods. University Of Minnesota.

13. Khurmi, R. S., & Gupta, J. K. (2005). *A Textbook Of Machine Design.* New Delhi: Eurasia Publishing House.

14. Krause, S. (2012). *Steel Bridge Design Handbook: Steel Bridge Fabrication.* Washington D.C.

15. Lavoie , T., & Jean, C. (2007). How To Keep Hydraulic Presses Running . The Fabricator.

16. Nisbett, B. (2006). *Mechanical Engineering Shigley's Mechanical Engineering Design* (8th Ed.). Mcgraw–Hill Primis.

17. Payne, B. (2013, September 18). *Advantages And Disadvantages Of Automation In Manufacturing*. Retrieved From Vista Industrial Products,Inc.: Http://Www.Vista-Industrial.Com/Blog/Advantages-And-Disadvantages-Of-Automation-In-Manufacturing/

18. Prajapati, M. (2015, September 26). *AUTOMATIC PNEUMATIC MACHINE USING PLC*. Retrieved From Academia: Http://Www.Academia.Edu/10761446/AUTOMATIC_PNEUMATIC_MACHINE_USING_PLC

19. *Press Maintenance Checklist Used In Performing Routine Maintenance On Punch Presses.* (N.D.). Retrieved From Stampingworld.Com.

20. Satalkar, A. B., Shar, M. R., Thoke, A. M., Sul, A. J., Gadge, R. R., & Bhane , A. B. (2015, April). Design & Fabrication Of Electromagnetic Punching Machine For Industrial Appliction. *International Journal Of Emerging Technology And Advanced Engineering, 5*(4), 1.

21. Suchy, I. (2006). *Handbook Of Die Design.* New York: Mcgraw-Hill.
22. Sukiran, S. N. (2010). *Design And Fabricate Of Pneumatic Punching Tool.* Melaka: Universiti Teknikal Malaysia Melaka.
23. Tank, A. N., & DHAMSANI, V. (N.D.). *PRODUCTION Technology (2161909).* Rajkot: Darshan Institute Of Engineering & Technology.
24. The Hong Kong Polytechnic University Industrial Centre. (2012). IC LEARNING SERIES. *Sheet Metal Fabrication*.
25. Verlags, J. R. (1996). Punching:Classic sheet metalprocessing in new dimensions-punching, nibbling, forming. *The Fascinating world of Sheet Metal*, 42. Ditzingen: TRUMPF GmbH +Co. KG.

Acknowledgements
I would like to thank the company that I worked with for data gathering.

Biography

Tawanda Mushiri is a PhD student at the University of Johannesburg in the field of fuzzy logic systems and maintenance, is a Lecturer at the University of Zimbabwe teaching Machine Dynamics, Solid Mechanics and Machine Design. His research activities and interests are in Artificial intelligence, Automation, Design and Maintenance engineering Contacted at tawanda.mushiri@gmail.com / tawandamushiri123@hotmail.com

Romana E. Mundondi is a Mechanical Engineering Graduate at the University of Zimbabwe (2016). Contacted at: cae.ethelr@msn.com

Charles Mbohwa is currently a Full Professor of Sustainability Engineering and Engineering Management at the University of Johannesburg, South Africa. Contacted at cmbohwa@uj.ac.za